RF Characteristics of the APS Storage Ring Isolation Valve

J.J.SONG
Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439

March 31, 1993

Abstract

The RF impedance of the sector isolation valve of the APS storage ring system was measured by the wire method with a synthetic pulse technique [1]. The coupling impedance as well as the energy loss of the isolation valve with and without an RF liner or screen, and the flange gap of the various sizes was calculated from the measurements. There appear to be resonances at certain frequencies in the absence of an RF liner that might cause an unacceptably large coupling impedance. Data with various sizes of the flange gap show that a good RF contact around any flange is necessary. The results also are compared with computer simulation from MAFIA. The measured impedance due to the RF liner alone is within 0.2 % of the total APS impedance budget [2].

I. INTRODUCTION

The beam coupling impedance must be kept small so that the desired operating current (a maximum of 300 mA with a lifetime of at least 10 hrs) can be achieved. To reduce the coupling impedance of the vacuum components in the APS storage ring, many of the vacuum components have RF shielding. Those are typically bellow liners, RF isolation valves, RF ion pumps, and screened photon absorbers as summarized and presented at the APS Accelerator Advisory Committee Meeting on

Nov. 11^{th} - 12^{th}, 1991 [3]. Among the concerns of RF shielding structure are vacuum, synchrotron radiation, RF heating, and coupling impedance. But the computation on the coupling impedance is not easy to do due to the complexity of the shielding structure, even though some calculation has been done by W. Chou [4].

II. LOSS PARAMETER AND IMPEDANCE

For a given particle beam bunch with charge, q, the energy loss of the bunch is

$$\Delta E = kq^2 = 2Z_L q^2 \frac{\int I_1(I_1-I_2)\ dt}{(\int I_2\ dt)^2} \qquad \text{(eV)}, \qquad (1)$$

where Z_L is the characteristic impedance of the transmission line or the wire running through the beam pipe, I_1 is the current flowing through the reference chamber (REF), I_2 is the current flowing through the device under test (DUT), and k is the loss parameter which is physically the energy loss in eV for a bunch with a unit charge passing through the vacuum component. Thus the longitudinal loss parameter, k, can be computed from measurements by the integration of the current over the pulse length such as:

$$k = 2Z_L \frac{\int I_1(I_1-I_2)\ dt}{(\int I_2\ dt)^2} \qquad \text{(V/pc)}. \qquad (2)$$

It must be pointed out that k is also a function of particle bunch length, σ. The power loss of one bunch can be calculated from eq. (1),

$$P_b = \Delta E/T_o = I_b^2 Z_{tot} \qquad \text{(W)}, \qquad (3)$$

where T_o is the period of the revolution of the beam around the storage ring, $I_b = q/T_o$ is the average beam current, and Z_{tot} is the total impedance. It should be noted that the total impedance for a vacuum component is the sum of the individual mode impedance weighted by the frequency spectrum of the exciting bunch.

Alternatively, the broadband impedance, $\underline{Z}$, [4] represents the impedance of the non-resonant device (e.g. any little discontinuity around the storage ring), which is given as:

$$\underline{Z} = \frac{Z(\omega)}{n} \qquad (\Omega), \qquad (4)$$

assuming that Q=1, where $n = \omega/2\pi f_o$ and $f_o = 1/T_o$ is the revolution frequency of the beam in the storage ring and $Z(\omega)$ is the individual mode impedance of the DUT in the frequency domain (FD). $Z(\omega)$ can also be computed from the measurements,

$$Z(\omega) = 2Z_L \frac{[I_1(\omega)-I_2(\omega)]}{I_2(\omega)} \qquad (\Omega), \qquad (5)$$

where $I_1(\omega)$ and $I_2(\omega)$ are the current measured in the FD with the REF and the DUT, respectively. The wake potential is defined as the integrated perturbed longitudinal electric field acting on the beam bunch with a unit charge and can be also derived by transforming eq. (5) into the time domain (TD),

$$W_b(t) = -\frac{2Z_L\ [I_1(t)-I_2(t)]}{q} \qquad (V/pc). \qquad (6)$$

III. EXPERIMENTAL SETUP and MEASUREMENTS

A VAT isolation valve (model S-47) [5] was tested to evaluate the RF characteristics of the RF liner. The VAT valve will be used to isolate one sector of the APS storage ring (SR) from another to keep ultra-high vacuum in the beamline. The isolation valves in the SR will each have an RF liner that provides a constant aperture through the valve in the open position. Fig. 1-1 is a cross section view of the prototype isolation valve, showing the RF liner when the valve is *partially* opened. An RF liner of the model S-47 consists of 64 shielding screens of 1.8 mm width, 4.3 cm long, 1.3 mm gap, and one tenth of mm thick. More detailed specifications can be found in reference [6].

As depicted in Fig. 2, a Network Analyzer (HP 8510B) was used to measure the two-port S-parameters of the DUT. All the data was transferred to the PC 486 computer for data analysis, using the HP Basic 6.0 program language. The measurements were done in the FD to obtain the impedance ($Z(\omega)$), and then the IFFT (inverse Fast Fourier Transform) gave a synthetic pulse for the energy loss factor calculation, k. Detailed procedures for the measurements are given in reference [7].

The RF measurement with S-47 was done against the standard valve that has no RF liner. The measurement assembly is shown in Fig. 1-2, with the prototype isolation valve connected to the short section of the beam pipe. This allows separation of possible multiple reflection from any other location besides the DUT. The other pipe is the reference beam chamber of the same length.

IV. RESULTS and DISCUSSION

The typical transmission data (S_{21}) in the frequency domain is shown in Fig. 3-1. The top curve comes from the reference beam chamber and the bottom curve is from the standard valve without an RF liner. As seen, there are resonances at 2.3, 5.9, and 9.4 GHz in the valve. These are due to the large opening into the actuator section of the valve. The *Q*s of some of these resonances are high enough to unsatisfactorily lower the threshold beam currents for multibunch instabilities (see Fig. 4-1). The RF liner in the valve solves the problem, as shown in Fig. 4-2. There are no cavity-like resonances, but the broadband impedance of the DUT has a maximum of $Z/n \sim 0.002\ \Omega$.

Gaps exist at the flanges between the isolation valve and the short reference beam chamber. This generates a weak peak around 2 GHz (see Fig. 4-2). The effect of a gap is illustrated in Fig. 3-2. The reflection data (S_{11} & S_{22}) in the TD are measured when the gap on the side of port 2 is filled with a gasket but the other side isn't. Without the gasket there is another reflection near the main reflection at 4 ns. The main reflection is from the valve itself. The measured impedance due to the whole system (gasket + valve) was about 4 X 10^{-4} Ω (see Fig. 5-1). One can further reduce the impedance of the gap by having an RF-type gasket. Also, using the Gating function of the HP 8510, the impedance contribution due to the valve itself is separated from the gasket, as shown in Fig. 5-2.

The loss factor, k, was calculated from the measurements in the TD. These are summarized in Table 1.

Table 1 Impedance and Loss Factor for the Isolation Valve

Isolation Valve	Impedance Z/n (Ω)	Loss Factor K(V/pC)
w/o RF Liner, Gasket	0.08	0.1
w RF Liner, but w/o Gasket	0.002	0.01
w RF Liner, Gasket, but no Gating	4 x 10^{-4}	4 x 10^{-3}
w RF Liner, Gasket, & Gating	4 x 10^{-5}	not available

The interesting thing is that one can see the bunch length-dependence of the loss factor as plotted in Fig. 6. This was done by varying the frequency span to get different synthetic pulse lengths. As seen, the beam bunch is lengthened in order to compensate the energy loss of the beam.

V. ACKNOWLEDGMENTS

The author would like to thank J. W. Howell for his mechanical engineering support. Also thanks must be given to Don Voss, Ed Wallace, and Portia Young for their technical support. This work was supported by the U.S. Department of Energy, Office of Basic Sciences, under Contract W-31-109-ENG-38.

VI. REFERENCES

[1] J. J. SONG, "Experimental Study of Coupling Impedance, Part I Longitudinal Impedance Measurement Techniques," APS Light Source Note LS-201, ANL, Oct 11, 1991.

[2] L. C. TENG, "Impedance and Current Limitations," DOE Review of APS Project at Argonne National Lab., March 6-8, 1990.

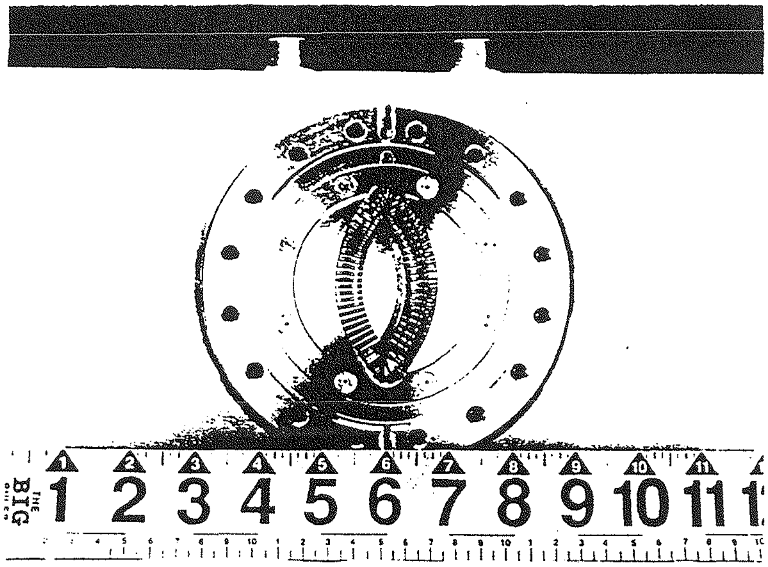
[3] J. W. Howell, "Storage Ring Vacuum Chamber - RF Shields," presented at the Accelerator Advisory Committee Meeting, Nov. 11-12, 1991.

[4] W. Chou, Y. Jin, "Impedance Studies-Part 4: The APS Impedance Budget," ANL-LS Note-115, 1988; "Impedance and Bunch Lengthening in the APS," in Proc. of the Impedance and Bunch Instability Workshop ANL-APS, Oct. 31-Nov. 1, 1989.

[5] VALVE DATA SHEET No. e-72453-01 for RF All-Metal Gate Valve from VAT.

[6] "Specification for Vacuum Valves for Booster and Storage Ring," Spec. N 20 50 35 04 from European Synchrotron Radiation Facility, 1990.

[7] J. SONG, "Experimental Study of Beam Impedance for the 7-GeV Advanced Photon Source (APS)," presented in Joint Symposia of IEEE-APS International, URSI Radio Science, and Nuclear EMP Meeting in Chicago, July 18-25, 1992.



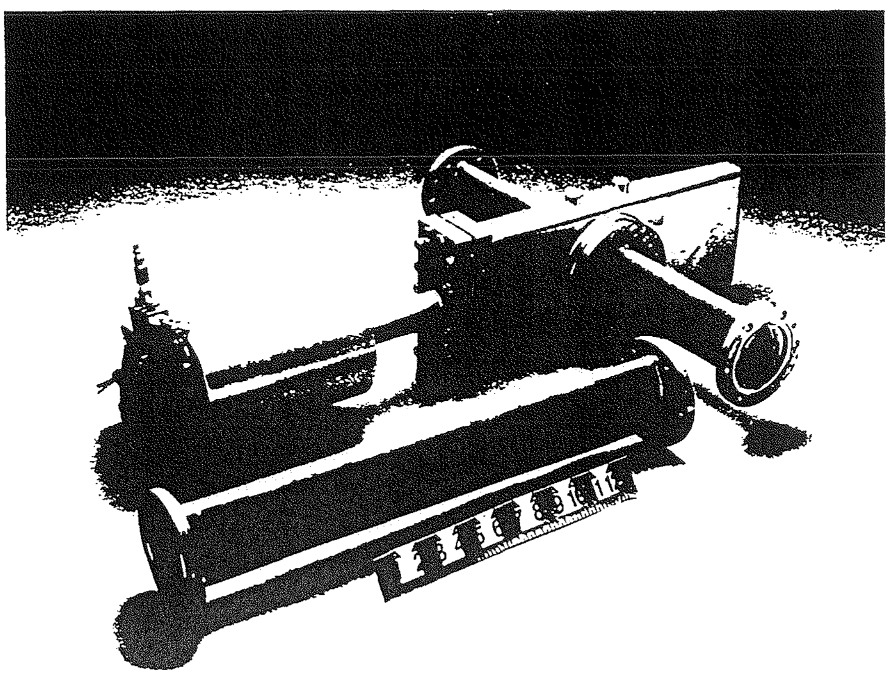


Fig.1-1) Cross section view of prototype isolation valve,
2) Measurement assembly of prototype isolation valve, and the reference beam pipe.

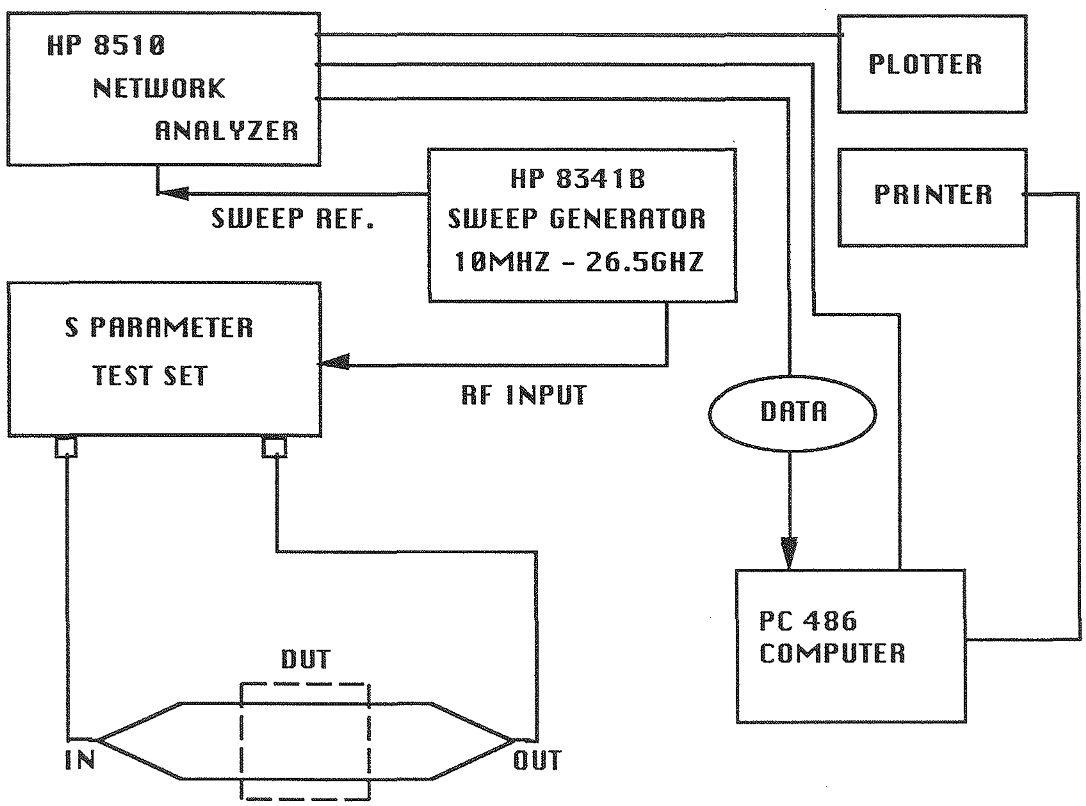
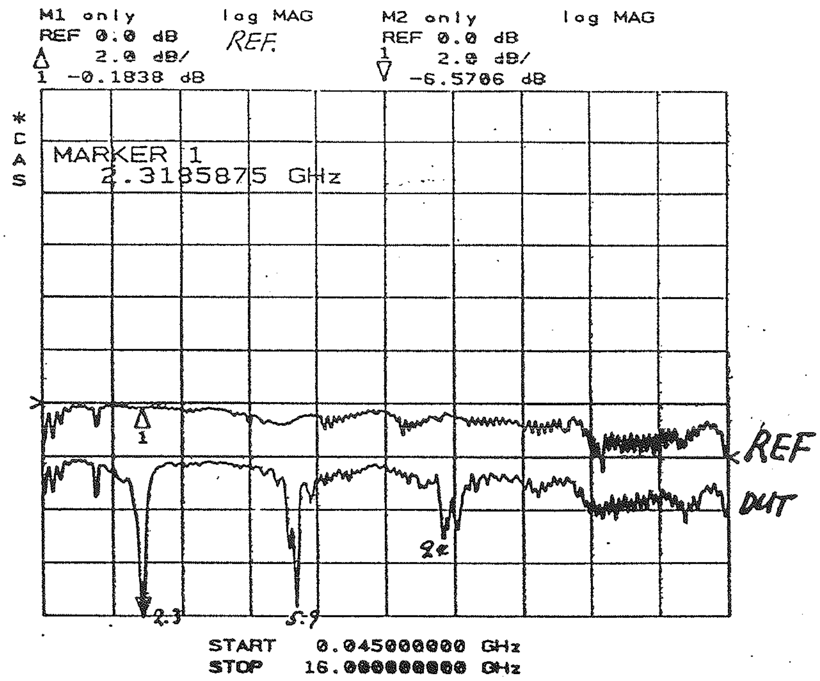


FIG. 2 EXPERIMENTAL SETUP ON A SYNTHETIC PULSE TECHNIQUE.



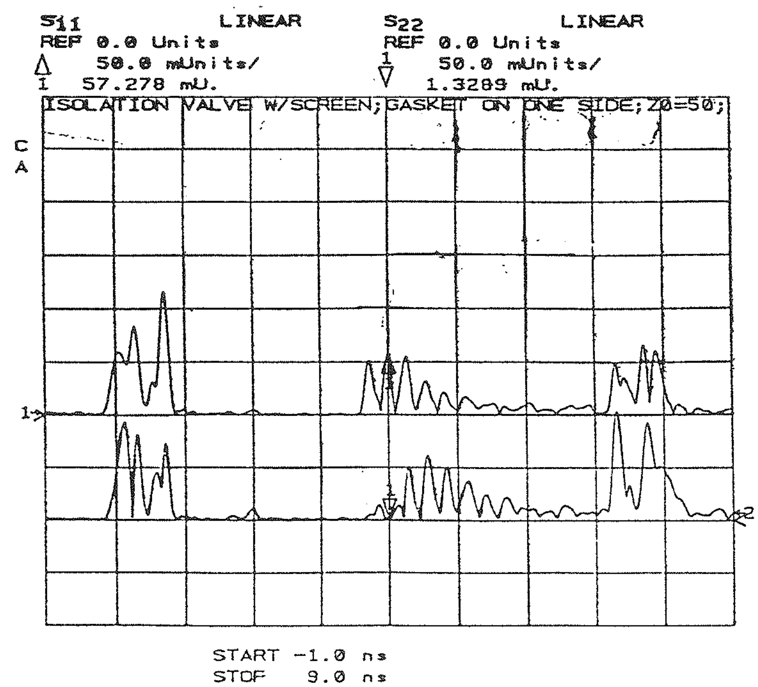
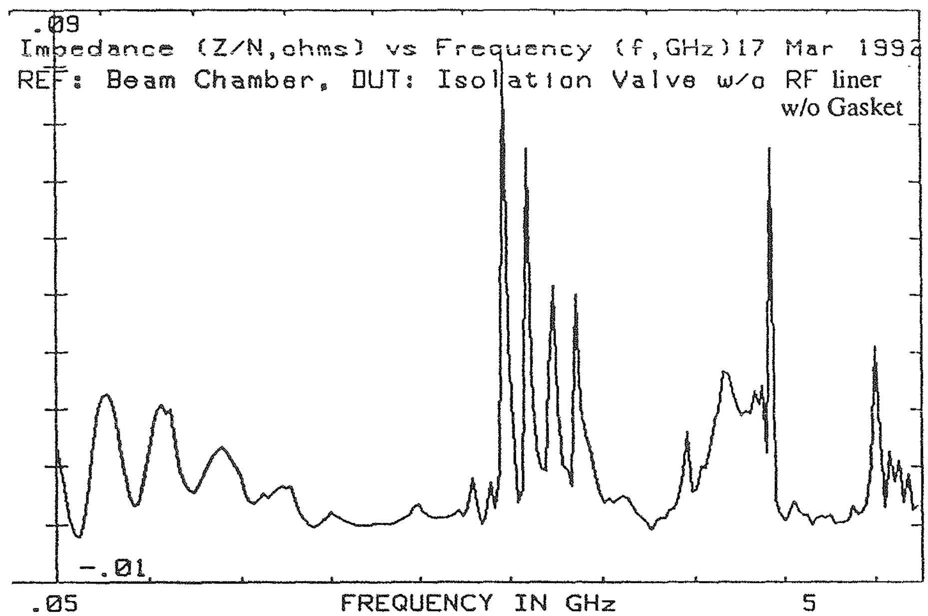


Fig.3-1) Typical transmission data (S_{21}) in the FD,
2) Reflection data (S_{11}&S_{22}) in the TD.



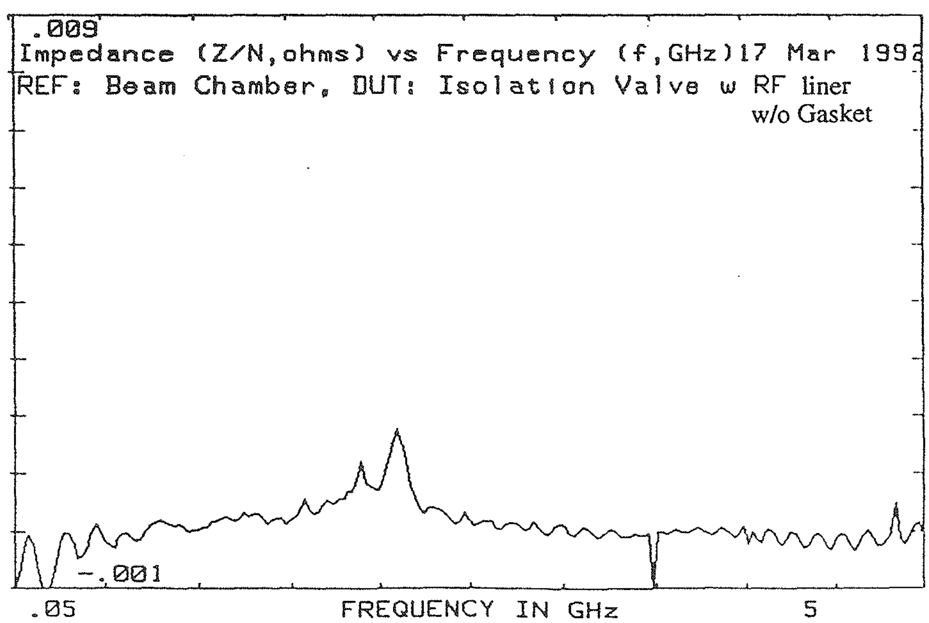
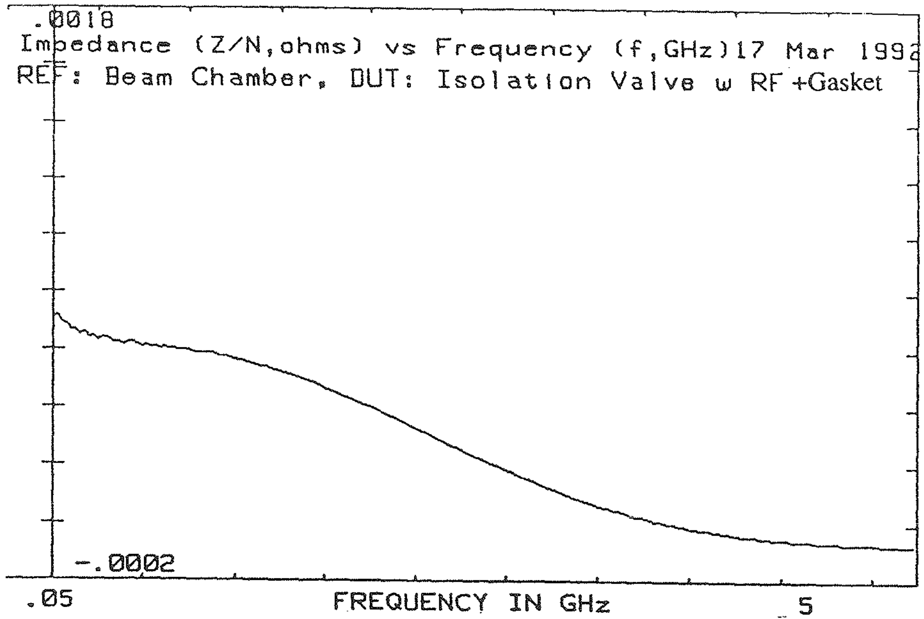


Fig.4-1) Measured impedance of isolation valve w/o RF liner,
2) Measured impedance of isolation valve with RF liner.



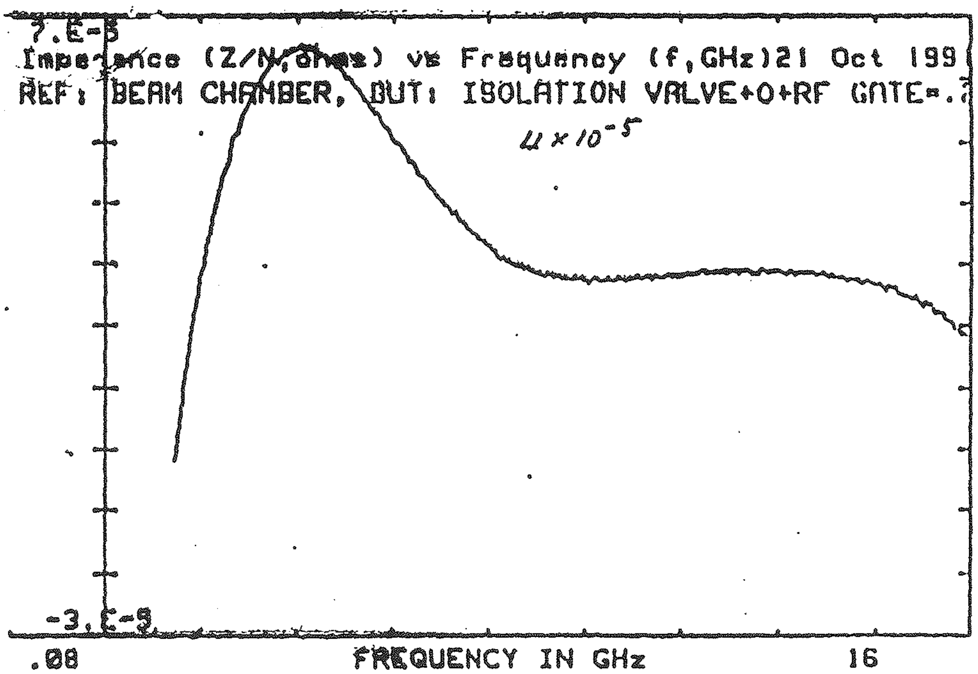


Fig.5-1) Measured impedance due to the whole system,

2) Measured impedance of isolation valve only.

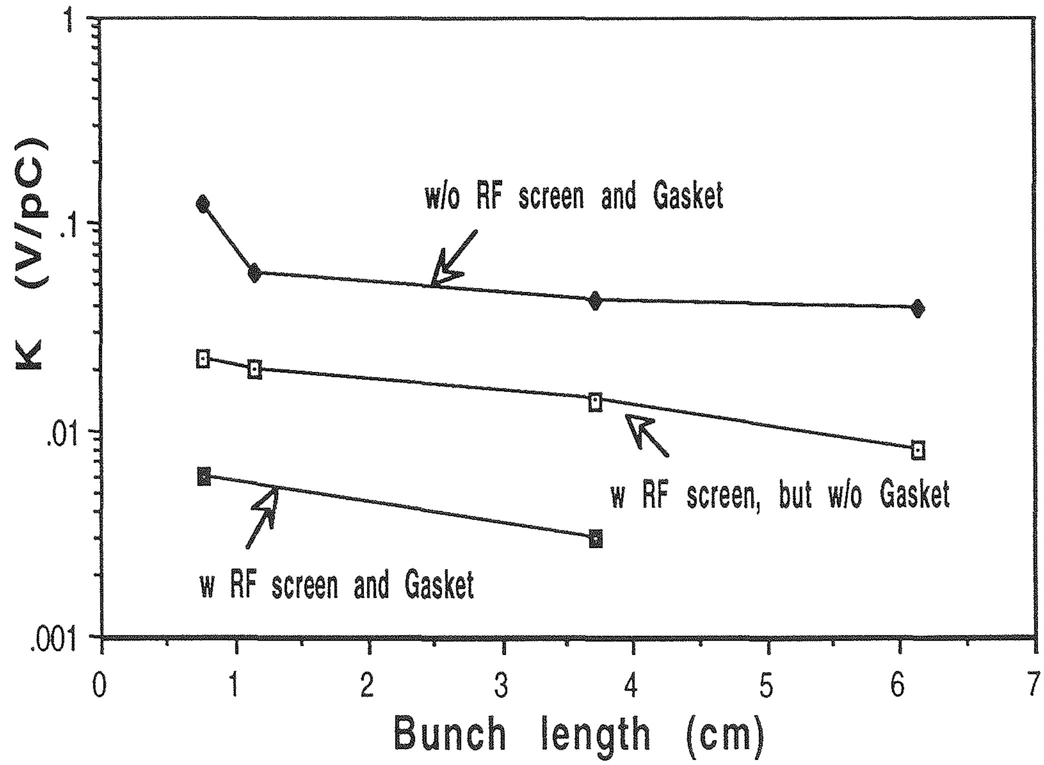


Fig.6 Loss factor vs Bunch Length for isolation valve.